**Propulsion Materials****Chemical Propulsion  
High-Temperature  
Materials****NASA Marshall Space Flight Center****Rhenium Nozzle Liners**

Radiation-cooled thrust chambers are used for a variety of chemical propulsion functions, including vehicle apogee insertion, reaction control for launch vehicles, and primary propulsion for planetary spacecraft. Thrust chamber performance is limited by the operating temperature capability of available materials. To ensure the robust health and durability of spacecraft in extreme environments over extended periods of time, materials for advanced chemical propulsion systems must be improved to operate under higher temperature conditions and to resist oxidation.

The state-of-the-art radiation-cooled thrust chamber is a rhenium (Re) structure lined on the internal hot wall with a thin layer of iridium (Ir). While this Ir/Re chamber shows significant improvement over previous silicide-coated niobium chambers, current Ir/Re chamber materials are limited to operating temperatures of  $\sim 2000^\circ\text{C}$  ( $3632^\circ\text{F}$ ). With thermal barrier coatings such as zirconium oxide ( $\text{ZrO}_2$ ) and hafnium oxide ( $\text{HfO}_2$ ), higher operating temperatures [up to  $2500^\circ\text{C}$  ( $4532^\circ\text{F}$ )] are possible, but conventional oxide coatings suffer

from cracking and spalling because of poor bonding. Researchers at Marshall Space Flight Center (MSFC) are generating a functional gradient material (FGM) that consists of a ceramic coating embedded in the Ir/Re liner. This new material may lead to in-space thrust chamber designs that are capable of operating at higher temperatures and for longer durations to meet the requirements of high-energy chemical propellants that will be used in future missions.

**Task Description**

This Advanced Materials for Exploration (AME) task builds on MSFC's successful development of high-temperature refractory metal-and-ceramic thermal barrier materials and processes. Researchers will advance the development and characterization of high-temperature materials and processes for Reaction Control Systems (RCSs) by

1. Designing a passively (radiation) cooled high-temperature oxygen/methane RCS
2. Fabricating full-scale thrust chambers using FGMs
3. Hot-firing the advanced thrust chambers to demonstrate improved performance.

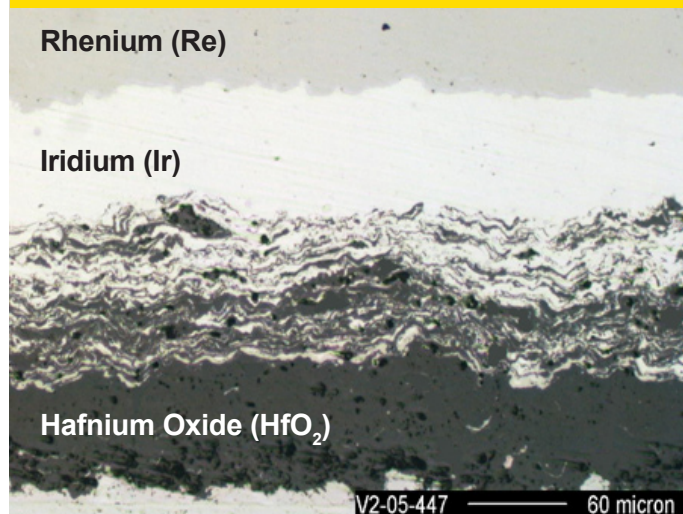
This 10-month task will culminate in September 2006.



Injector faceplates coated with functionally gradient materials ( $\text{NiCrAlY}$  and  $\text{ZrO}_2$ ) were exposed to 50 hot-fire tests at 1000 psig. Neither coating cracked, spalled, or discolored.

advanced materials for exploration

# CHEMICAL PROPULSION HIGH-TEMPERATURE MATERIALS

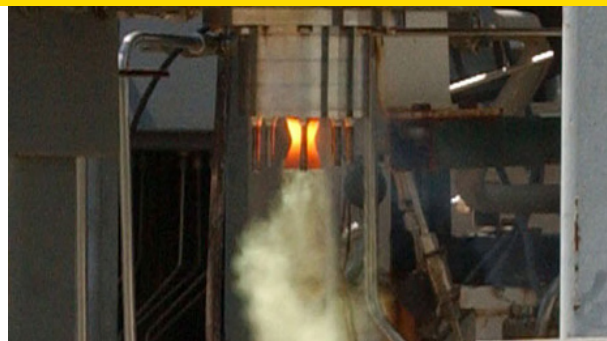


This micrograph shows the HfO<sub>2</sub>/Ir/Re functional gradient region (between the HfO<sub>2</sub> and Ir layers) as deposited by Vacuum Plasma Spray (VPS). The HfO<sub>2</sub> and Ir gradient improves the bond strength by minimizing stresses from thermal expansion mismatch.

## Anticipated Results

First, the research team will design, build, and validate the performance of a prototype 100-lbf RCS system, which will contain the advanced high-temperature, radiation-cooled thrust chamber. Next, researchers will optimize Vacuum Plasma Spray (VPS) and other proven net shape fabrication technologies to form the functionally graded Ir/Re/oxide chambers. Recent testing of VPS FGMs for chemical rocket engines has shown no oxidation or cracking after 200 hot-fire test cycles. Use of VPS will enable the creation of an integral FGM thermal barrier that will maximize operating temperature and oxidation resistance. One baseline Ir/Re thrust chamber and one advanced Ir/Re/oxide chamber will be fabricated with functional gradient combinations based on existing properties, temperature capability, chemical compatibility, and phase stability of the protective layers. The fabrication will take place at MSFC or Plasma Processes, Inc., in Huntsville, Alabama.

Hot-fire testing of both chambers, to be conducted at either MSFC or Orion Propulsion in Madison, Alabama, will consist of a series of 10 tests with hot-fire durations up to 30 seconds each. Hot-firing will be performed with oxygen/methane propellant, a high I<sub>sp</sub> fuel attractive to designers of Moon and Mars missions.



Ir/Re throat section during hot fire testing at MSFC.

The MSFC Materials and Processes Laboratory will conduct all characterization and materials testing to verify fabrication limits, material tolerances, microstructural phases, density, and defects as compared to previously fabricated subscale materials. The results will provide verification of the advanced thrust chamber fabrication processes and the ability of the functionally graded thermal barriers to provide improved performance over baseline Ir/Re and conventional oxide-coated Ir/Re chambers.

## Potential Future Activities

Potential follow-up activities to this effort include further optimization of the FGM and ceramic layer, high-temperature material property testing, joining, optimization of the Re structural material to provide improved high-temperature strength, and additional hot-fire testing with other advanced propellants.

## Capability Readiness Level (CRL)

Successful completion of this effort will advance these FGM barrier materials from a CRL of 2 to 4 or 5.

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